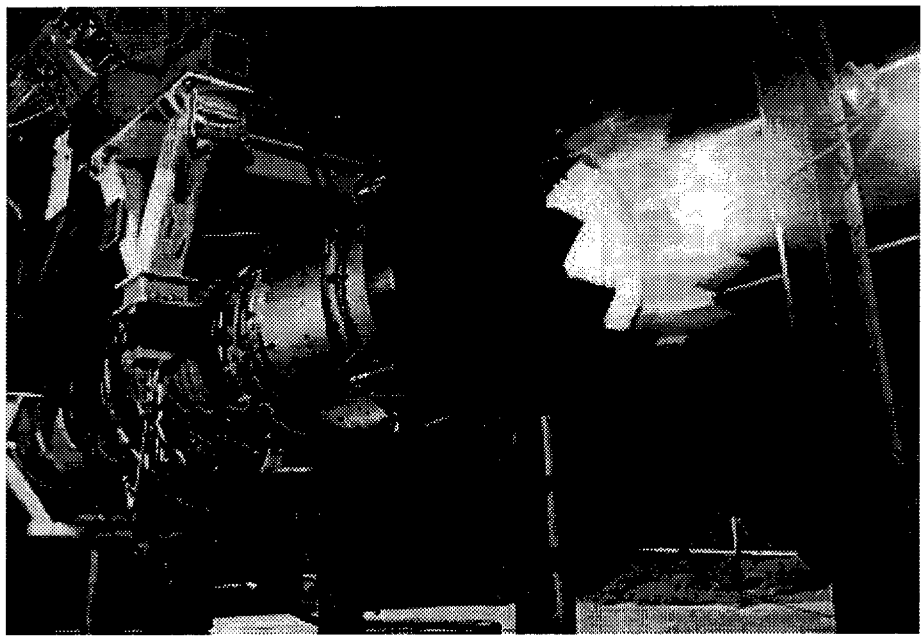
FY98
Aero Propulsion & Power Technology Area Plan



Air Force Research Laboratory
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Note

This Technology Area Plan (TAP) is a planning document based on the President's FY98 budget request. It does not reflect the impact of the FY98 congressional appropriations. You should consult WL/POM, DSN 785-2622 or commercial (937) 255-2622 for specific impacts that the FY98 appropriation may have had with regard to the contents of this particular TAP. This document is current as of 1 June 1997.

Internet access

An electronic copy of the most recent Aero Propulsion and Power TAP and other Air Force TAPs are now available on the world wide web (letters are case sensitive):

http://stbbs.wpafb.af.mil/STBBS/info/taps/taps.htm

Additional information concerning this and other technology areas are available on the Wright Laboratory home page:

http://www.wl.wpafb.af.mil/

On the cover

The advanced development engine shown under test is demonstrating a low signature axisymmetric nozzle. Compared to current production two-dimensional convergent/divergent technology, this nozzle has demonstrated 50% less weight, 60% less cost, 300 fewer parts, and is projected to be easier to maintain, support, and have longer part life. It is part of the Integrated High Performance Turbine Engine Technology (IHPTET) program that is a joint Air Force, Navy, Army, DARPA, NASA, and industry effort focused on developing technologies for more affordable, more robust, higher performance engines.

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13. ABSTRACT *(Maximum 200 words)*

The Aero Propulsion and Power Technology Area is responsible for developing air breathing propulsion and power technology for Air Force use. Besides developing new technologies, product centers are supported by helping acquire systems and providing expertise to help solve developmental problems. current research and development includes aircraft gas turbine engines (components, gas generators, technology demonstrator engines, fuels and lubricants), missile propulsion, (solid fuel ramjets, ducted rockets, and small turbine engines) , aircraft and missile power (electrical and mechanical power generation, conditioning and distribution, energy storage, and thermal management), and plasma physics.

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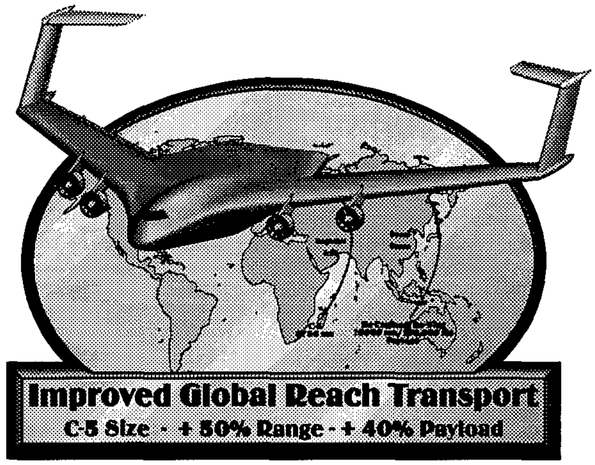
Visions & Opportunities

The Aero Propulsion and Power technology area is responsible for developing airbreathing propulsion and power technology for Air Force use, with a heritage reaching back to 1917. We are a proud part of Wright Laboratory, Aeronautical Systems Center, Air Force Materiel Command located at Wright-Patterson Air Force Base near Dayton, Ohio.



New capabilities through advanced propulsion

Despite many advances since the dawn of the jet age, the potential for turbopropulsion has been only partially realized. By around the turn of the century, we expect this potential in terms of propulsion capability to be doubled relative to a 1987 technology baseline. This will be achieved through the Integrated High Performance Turbine Engine Technology (IHPTET) program.

Started within DoD – with support from the Defense Advanced Research Projects Agency (DARPA), National Aeronautics and Space Administration (NASA), and the turbine engine industry – the IHPTET program focuses the nation's research and development (R&D) resources to provide dramatic increases in engine affordability, durability, and performance. IHPTET is structured to meet emerging aircraft and missile turbopropulsion needs – current and future, military and commercial. IHPTET enables:

- Upgraded and derivative engines – to enhance durability, performance, life, and survivability – that will lower cost of ownership and increase force effectiveness.
- New engines – with major emphasis on acquisition and maintenance cost reduction – that leads to revolutionary weapon system capabilities.
- Dual-use technologies – transferred from military applications – to improve commercial, industrial, and marine turbine engines.

As one looks far into the future (2025), the turbine engine will continue to play a critical role not only in our national defense, but in our U.S. national economy as well. Turbine engines will continue to revolutionize both military and commercial aircraft, will grow in usage for tanks, ships, and recreational vehicles and will become a vital source of electrical power generation throughout the world. The turbine engine will, in one way or another, enhance the lives of nearly every person on the planet.

New high speed airbreathing propulsion efforts are focused on the Air Force vision "Global Engagement – the ability to hit an adversary's strategic centers directly…the ability to bring intense firepower to bear over global distances within hours." In support of this vision, high speed airbreathing engines will provide the capability for sustained flight up to Mach 8 over long ranges using conventional hydrocarbon fuels. Some examples of revolutionary capabilities achievable through high Mach airbreathing propulsion include:

- High speed air-to-ground missiles that rapidly attack time critical and hardened or deeply buried targets from long and inherently safe standoff ranges.

- Light weight attack weapons that lead to force multiplication through increased range, loadout, and mission flexibility.
- Air-to-air missiles with significantly increased launch and no-escape zones, providing air superiority well into the next century.
- Global, fast reaction strike and reconnaissance aircraft that can operate from existing airfields within the United States, using conventional fuels.
- Lower stage propulsion for future military and commercial launch vehicles – enabling increased payloads and hence, more affordable access to space.

Fuels and lubrication will continue to be the "life blood" of gas turbines. Circulation of these fluids for aircraft thermal management will maintain the health and integrity of all systems. Future capabilities will include:

- A single, affordable high temperature capable jet fuel that eliminates fuel system deposits and related maintenance. This fuel will be applicable to both air and ground vehicles operating throughout all engine cycle temperatures and vehicle speeds.
- Improved combustors that operate at high temperatures while reducing fuel consumption and pollution.
- Lubrication systems with fewer parts that weigh 50% less than existing systems. Included will be alternative nonlubricated mechanical components – such as magnetic bearings.

An essential feature of today's and tomorrow's systems is electric power. Our vision in this area is found in the More Electric Aircraft (MEA). This initiative is focusing technology developments of the services, NASA, and industry for the entire range of aircraft power components. Already underway, these developments will provide substantial benefits to both the Air Force and the nation:

- Power-by-wire, via the MEA approach, that allows substantial reduction in aerospace ground support equipment and more than doubles reliability for aircraft power systems by eliminating existing on-board hydraulic, pneumatic, and mechanical power subsystems.
- Use of MEA technologies that offer about an additional 10% sortie rate for a typical wing of F-16s over a 30-day war.
- MEA technologies that transition to the operational fleet to extend the life of the aircraft and to reap improved reliability, maintainability, and supportability (RM&S).

This look towards the future gives insight to the breadth of work and vision of the Aero Propulsion and Power technology area. The program benefits all aspects of Air Force operations by providing balanced improvements in affordability, performance, and supportability. The technologies will continue to be adopted by the other services and the civilian sector, as they have been for decades.

This plan has been reviewed by all Air Force laboratory commanders/directors and reflects integrated Air Force technology planning. I request Air Force Acquisition Executive approval of the plan.

RICHARD W. DAVIS, Colonel, USAF
Commander
Wright Laboratory

RICHARD R. PAUL
Major General, USAF
Technology Executive Officer

Contents

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Introduction

Background

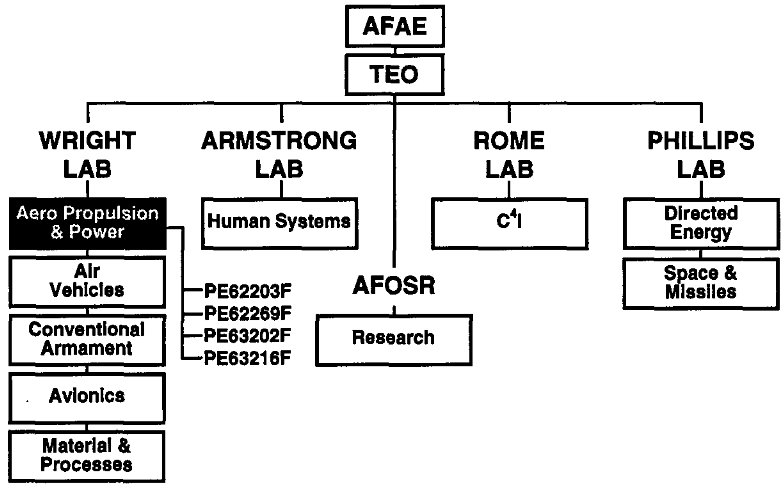

Figure 1.1: Air Force S&T Program Structure

Aero Propulsion and Power, highlighted in Figure 1.1, is an integral part of the Air Force (AF) Science and Technology (S&T) program. It is also a key component of the Air Platform technology area described in the Department of Defense (DoD) Technology Plan (DTAP) that documents the focus, content, and principal objectives of the overall DoD S&T effort. This DoD plan – as well as the Air Force program – is responsive to the S&T strategy issued by the Director of Defense Research and Engineering (DDR&E) and is in partnership with other government agencies, industry, and academia.

We play a major role in developing and executing Wright Laboratory's (WL) investment strategy that is based on guidance received from the Technology Executive Officer. This strategy complies with DoD guidance as reflected in the Basic Research Plan and the DTAP. It maintains a balanced S&T program in terms of basic research, exploratory development, and advanced development. It is responsive to documented "warfighter" needs, the changing defense budget, and an increasing need to develop more affordable, durable weapon systems, while avoiding costly R&D duplication. This strategy assumes buying fewer new systems and relying more on system upgrades using proven technological innovations.

Specific programmatic plans for guiding our investments in research and technologies are:

- Maintain the pace, meet the milestones, and achieve the technology goals established by DDR&E as part of a national S&T investment strategy. Full spectrum dominance is the key characteristic of this strategy for the U.S. armed forces of the 21st century.
- Address key recommendations of the Scientific Advisory Boards' (SABs') New World Vistas (NWV) – a study describing essential capabilities needed by the Air Force of the 21st century.
- Address recommendations of other evolving long-range planning initiatives (e.g., Air Force 2025 – a study directed by the Chief of Staff of the Air Force to envision capabilities in air, space, and information power in the far future; and Joint Vision 2010 – a comprehensive look at tomorrow's warfare – the vision of the chairman of the Joint Chiefs of Staff of how joint forces will fight in the 21st century).
- Continue the momentum in applicable Air Force special emphasis/focus areas – for our technology area this applies to aging aircraft and high cycle fatigue.

Our technology area – involving the research and development of turbine engines, fuels and lubricants, high speed propulsion, and aircraft power – is responsive to this S&T guidance. Compliance is assured through frequent reviews with DDR&E, Air Force Materiel Command (AFMC), SAB panels, and AFOSR.

Aero propulsion and power technologies are common to all services. Most Army, Navy, and commercial engines are derivatives of Air Force power plants that we helped to conceive, develop, and/or demonstrate. All services use our developed fuels and lubricants. These

numerous applications are primarily due to proven, practical technologies being available and affordable when needed by the users.

Joint programs are the most common business practice within this technology area. Examples include the Integrated High Performance Turbine Engine Technology (IHPTET) program, the More Electric Aircraft (MEA) initiative, and the evolving Wright Laboratory Hypersonic Technology (HyTech) program. All of these efforts successfully leverage precious resources to include people, facilities, and R&D dollars.

We make every attempt to be responsive to relevant user deficiencies/needs. These are identified via the Air Force Modernization Planning Process (AFMPP) and are articulated through the Technology Master Process (TMP) being implemented by AFMC. The TMP provides a comprehensive process for technology development, transition, and application/insertion having strong user endorsement. The TMP has allowed us to tie our technologies more closely with the needs of the warfighters.

The process is mature after 3 years of implementation. The major commands have developed Mission Area Plans (MAPs) that document user mission "capability deficiencies." The Technology Planning Integrated Product Teams (TPIPTs) – led by the product centers with participation from laboratories, test centers, logistics centers, and major commands – continuously examine these deficiencies, roadmap system level solutions, and identify the technology needs associated with the postulated system solutions or functions.

The FY97 AFMPP – ASC Concept Call – Deficiency Data (U) report provides a consolidated list of these deficiencies prepared by the Aeronautical Systems Center (ASC) for air vehicles and weapons. This document is classified Secret/Noforn and is available to the DoD and U.S. DoD contractors. In general terms, aero propulsion and power addresses customer needs to enhance engine performance, reduce signatures, improve range, increase durability, lower cost, reduced hazardous materials, reduce aircraft support equipment, and provide missile propulsion capabilities to engage targets at extended range and kill time critical targets. More specific details are discussed in the thrust chapters that follow.

Accomplishments have been plentiful. During the past year, we exceeded IHPTET's Phase I goals for both turboprop/turboshaft and expendable engines. These include increase in horsepower-to-weight ratio and specific thrust, and reduction in fuel burn. IHPTET Phase I is now complete and Phase II is well underway with cost reduction goals. We continue to work with our users to speed the transition of turbine cooling and exhaust nozzle technologies into current and future engine families. Finally, we continue to push the development of high temperature electronics providing smart actuators and control technologies to work in the hostile engine environment.

Significant progress was made on development of a higher thermal stability JP-8 fuel (JP-8+100). While intended to provide additional margin in thermal stability and heat sink for future aircraft such as the F-22 and the Joint Strike Fighter (JSF), JP-8+100 continues to demonstrate significant benefits for current aircraft. Flight evaluations continued in F-15s, F-16s, T-37s, T-38s, A-10s, and C-130s. At Sheppard AFB, TX, the use of the +100 additive package led to a 40% reduction in T-38 augmentor no-lights. For the other aircraft, maintenance personnel continue to report improved overall cleanliness for all engines on JP-8+100 versus regular JP-8.

The need for improved missile kinematic performance is being fulfilled by successfully developing ducted rocket propulsion technology for advanced air-to-air and air-to-ground weapons. The Variable Flow Ducted Rocket (VFDR) has successfully demonstrated this technology through extensive ground testing of flight weight engines. Much of this technology is

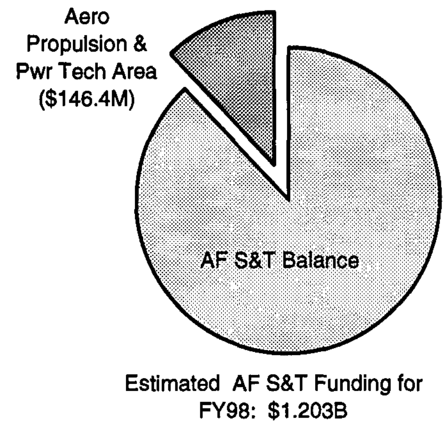

Figure 1.2: Aero Propulsion & Power S&T Funds vs. AF S&T Funds

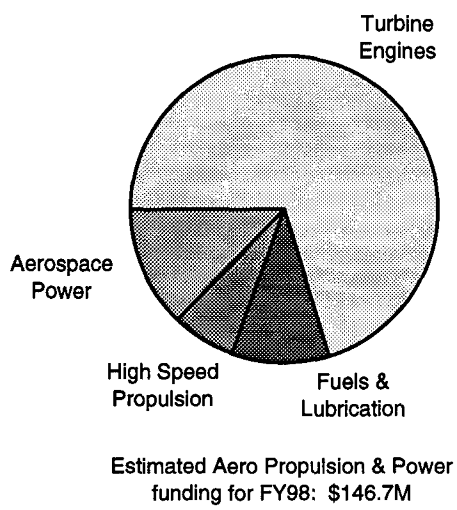

Figure 1.3: Major Technology Thrusts Funding

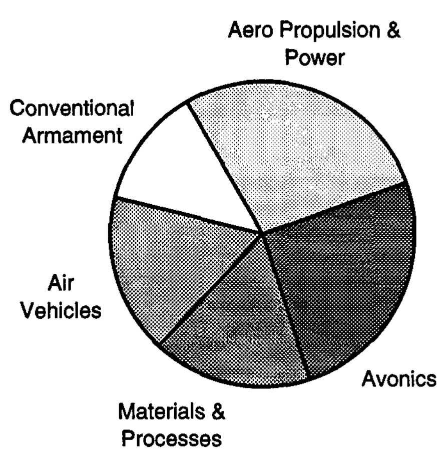

Figure 1.4: Technology Area Funding within Wright Laboratory

being considered for the UK Future Medium Range Air-to-Air Missile (FMRAAM), and may therefore be used in future USAF air-to-air missiles.

R&D success is achieved when relevant technology is truly available for transition to the operational world. The maintenance free battery program successfully transitioned a maintenance free battery/charger system to the E-8 Joint Strategic Target and Recognition System (JSTARS) last year. In addition to the battery program, development of a highly reliable 270-Vdc electrical power distribution system has been strongly endorsed by the F-22 System Program Office (SPO), who have already benefited from issues surfaced by our power distribution ground demonstrator. Also, we continue to work with the C-141 Electric Starlifter program in retrofitting with new electrically-driven, integrated actuator packages, where 400 hours of flight have been achieved for AMC missions.

Regarding funding, Figure 1.2 illustrates the FY98 investment in the Air Force science and technology (AF S&T) program devoted to Aero Propulsion and Power. It represents 12% of the overall AF S&T budget This funding along with program milestones are contained in the following Descriptive Summaries provided to Congress:

- PE62203F - Aerospace Propulsion,
- PE62269F - Hypersonic Technology Program,
- PE63202F - Aircraft Propulsion Subsystem Integration, and
- PE63216F - Aerospace and Propulsion Technology.

The funding supports our four thrusts: (1) Turbine Engines, (2) Fuels and Lubrication, (3) High Speed Propulsion, and (4) Aerospace Power. They were created to exploit new technologies, while maintaining a balance with user needs. Figure 1.3 shows how Air Force S&T funds – including payroll and operation costs – are apportioned across these thrusts. Figure 1.4 has been included to illustrate the relative investment in Aero Propulsion & Power (28%) within Wright Laboratory.

Work in our technology area is augmented by a very active Small Business Innovation Research (SBIR) program. We currently fund over 46 active contracts valued at $11 million. The Air Force Office of Scientific Research (AFOSR) sponsors eight basic research projects valued at about $5 million per

fiscal year. This work is reported in the AFOSR Research Technology Area Plan (TAP). The Reliability & Maintainability Technology Insertion Program (RAMTIP) provides an additional $1 million to develop electric actuators and ceramic bearings. Discussed next are the objectives and contents of each thrust.

THRUST 1, Turbine Engines, provides the Air Force's (and most of the nation's) turbine engine technology base. Work is centered on the IHPTET program. This is DoD's highest priority effort in air breathing propulsion R&D. IHPTET encompasses the three services, DARPA, NASA, and the domestic turbine engine manufacturers. It offers breakthrough opportunities and is revolutionizing flight vehicle range, payload, agility, survivability, supportability, and affordability. A fully supported IHPTET program will ensure American dominance in this key technology area well into the next century.

THRUST 2, Fuels and Lubrication, supports DoD user requirements with improved, environmentally acceptable fuels, combustors, lubricants, and lubrication systems. Thrust goals emphasize reducing both maintenance and waste in current systems while providing higher temperature capability to support current and future weapon systems. A far-term coal-derived fuel program is being pursued to assure national energy self-reliance. Being addressed are environmental concerns, fuel costs, and logistics. Much of this technology transitions directly to operational systems with little or no additional development.

THRUST 3, High Speed Propulsion, provides Mach 0 to 8 airbreathing engine technology for missiles, aircraft, UAVs, and space launch systems. As the Air Force's only work in high speed airbreathing propulsion, this thrust plays a vital role in retaining the research base necessary to maintain our technological edge and to satisfy documented Air Force needs. A major portion of this thrust supports the Hypersonic Technology (HyTech) Program. This nationally coordinated effort was established by the Secretary of the Air Force to develop and demonstrate critical technologies that "enable sustained hypersonic flight." Airbreathing propulsion which operates up to Mach 8 using conventional hydrocarbon fuels is the key enabling technology focus of the HyTech program. The program will culminate with the demonstration of a flight-type scramjet propulsion system for a fast reaction, Mach 8 air-to-ground missile. In addition to the HyTech program, advanced cycles, such as the pulse detonation engine, are being developed to provide low cost propulsion for missiles and UAVs. Technical information and data are being exchanged with the Phillips Laboratory (Propulsion Directorate) to support their development of the pulse detonation rocket and rocket based combined cycle engine for affordable access to space.

THRUST 4, Aerospace Power, provides a common technology base from which power systems can be developed with confidence. The More Electric Aircraft initiative is a major work effort focused on air vehicles. Led by the Air Force, this initiative leverages support from the three services, NASA, and over 50 individual companies. Emphasis is on reducing the cost of force projection by doubling power system reliability and reducing our dependence on aircraft ground support equipment. Also, this thrust – as well as 1 and 2 – combine resources toward the demonstration of distributed electric engine controls, magnetic bearings, and internal starter/generators. These are enabling technologies supporting the achievement of IHPTET's and MEA's aggressive goals.

Relationship to other Technology Programs

Aero Propulsion and Power is a broad-based area that deals primarily with energy and its transformation. As such, it is closely linked with most of the other Air Force technology areas. Foremost of these are Air Vehicles (engine/airframe integration, thermal management, aircraft subsystems, flight control, fire suppression), Conventional Armament (missile batteries, engines), Materials and Processes (engine materials, lubricants, fire suppression, magnetic

materials, conducting materials), Manufacturing Technology (producibility), Avionics (high temperature electronics), Directed Energy (high power technology), Space and Missiles (kinetics, plasma effects, electrical power management, combined/advanced cycle engines), and the AFOSR managed technology area, Research (compressors, heat transfer, combustion, plasma physics). These linkages have been extended to the other services and further documented under the DoD technology plan.

Turbine engine R&D, through IHPTET, is thoroughly integrated with that of other government organizations and with the nation's manufacturers. The area typically leverages slightly more than its annual funding through contractor Independent Research and Development (IR&D) efforts. IR&D is a major contributor in maintaining our technological superiority and is applied to both military and commercial products. These efforts provide aircraft engine enhancements that otherwise would not be available from DoD funds.

Joint planning activities for the More Electric Initiative have formed a strong coalition between the services and NASA. The Army now relies on the Air Force for all of its technology developments for aviation electrical power systems. Additionally, the Army and Air Force are teamed to insert more electric technologies into electric vehicles for tactical and nontactical applications. The Navy, Air Force, and DARPA are jointly developing advance power electronics for onboard ship power conditioning.

The Joint Aeronautical Commanders' Group's More Electric Initiative Joint Planning Team continues to benefit by leveraging the nation's IR&D resources in electric subsystems and components. Funding in More Electric IR&D technologies exceeds $20M per year across the participating companies.

All four thrusts have international ties with emphasis on those areas where we have the most to gain. Most important is high speed propulsion, an area that – because of its breakthrough potential – many other countries are aggressively pursuing. Congressional earmarked funds (Nunn amendment) are supporting international programs to augment our ducted rocket efforts with higher energy propellants, simplicity, reliability, and reduced costs. Also, several international data exchange agreements exist to enhance our ramjet, ducted rocket, and combined-cycle engine concepts. These efforts help us to gain technical insight and to leverage limited R&D dollars.

In regard to the civilian sector, spin-offs will continue to be both common and important. A large portion of our developed technologies eventually wind up in commercial airplanes. Indeed, Air Force S&T is largely responsible for maintaining American dominance and a favorable balance of trade in this key field. This is also beneficial, in that the Air Force often buys "commercial" aircraft and engines for its airlift fleet.

Changes from Last Year

Continuing to mature are the Defense Technology Objectives (DTOs) that were jointly formulated by the services and are reviewed yearly by DDR&E. They state specific technology advancements to be developed and/or demonstrated that solves a technical barrier for a specified customer. We have seven DTOs:

- Fighter/Attack/Strike Propulsion,
- Transport/Patrol/Helicopter Propulsion,
- Cruise Missile/Expendable Propulsion,
- Improved JP-8 Fuel,
- High Heat Sink Fuels (JP-900/Endothermic),
- Hydrocarbon Scramjet Missile Propulsion, and
- Aircraft Power.

The DTOs account for over 98% of our S&T dollars and are joint/coordinated with the other services. They help us link technology efforts to specific goals that will provide the warfighter with discernible air vehicle capabilities.

Continuing this year is the expanded interest in solving durability issues – specifically, high cycle fatigue in turbine engines. This issue has been raised to the highest levels within DoD, and a National Coordinating Committee has been formed to quantitatively define the challenge and identify necessary technology programs.

We have placed higher priority on the transition of IHPTET and MEA technologies to multiple customers, both military and commercial. Of special note is the Joint Strike Fighter (JSF) program – that will demonstrate key propulsion and power technologies and system designs necessary to meet both Air Force and Navy next generation strike aircraft needs. IHPTET and MEA technologies and demonstrations supply the foundation of the JSF propulsion and power effort.

Per DDR&E guidance from the recent Technology Area Review and Assessment (TARA), we will identify, if any, UAV-unique propulsion technology needs and factor into the IHPTET program if warranted. Programs to be evaluated include the Joint Warfighting Science and Technology Plan's Joint Tactical UAV and the High Altitude Endurance UAV.

Another major change from last year is the virtual elimination of our primary ramjet and turbo-based combined cycle engine development activities due to Air Force S&T funding cuts. Ramjet related technology development in the Air Force is now primarily limited to basic research (6.1). The turbo-based combined cycle work is being shifted to NASA sponsorship (if funding is available).

Consortia between government/industry/academia are forming to work common technical issues. These consortia are cost effective partnerships that require large resources of capital. The result is win-win for the participants and for the country. Current partnerships are in the areas of advanced composites, instrumentation, forced response, life prediction, and damping.

With the draw-down in defense, we have become more actively involved in forming partnerships with industry and academia. We are taking advantage of our in-house strengths to develop Cooperative Research and Development Agreements (CRDAs) with nonfederal partners to enhance technology transfer. Neither the military nor commercial world can afford to fully fund all research and development efforts required to maintain our technological edge in the international market. However, since much of our technology has dual-use potential, we are able to leverage our resources with industry in order to develop technologies that benefit both military and commercial applications. This enables the nation to effectively compete in the international market.

Summary

Our technology area plan describes a well-balanced program that:

- Is focused on user priorities,
- Is responsive to policy guidance,
- Exploits technological opportunities and revolutionary approaches, and
- Leverages budgets through extensive cooperation with other laboratories, agencies, and industry.

The chapters that follow highlight our four thrusts. Described are user needs/deficiencies, goals, major accomplishments, changes from last year, and milestones. These chapters represent our strategy to meet the current and future needs for defense research and development.

Thrust One – Turbine Engines

User Needs

Airbreathing propulsion is a key DoD technology that this thrust supports through the Integrated High Performance Turbine Engine Technology (IHPTET) program. IHPTET is a joint DoD/NASA/industry program focused on developing turbine engine technologies for more affordable, more durable, higher performance military propulsion systems. Because gas turbine engine technology is largely applicable to both military and civil aircraft, achieving the IHPTET goals will help to ensure continued U.S. preeminence in the increasingly competitive international marketplace well into the 21st century. IHPTET is strongly supported by Congress and is often cited as the premier example of a well coordinated government-industry technology development program. It offers step-wise (phased) technology transitions for various engine classes to targeted weapon system applications as shown in Figure 2.1.

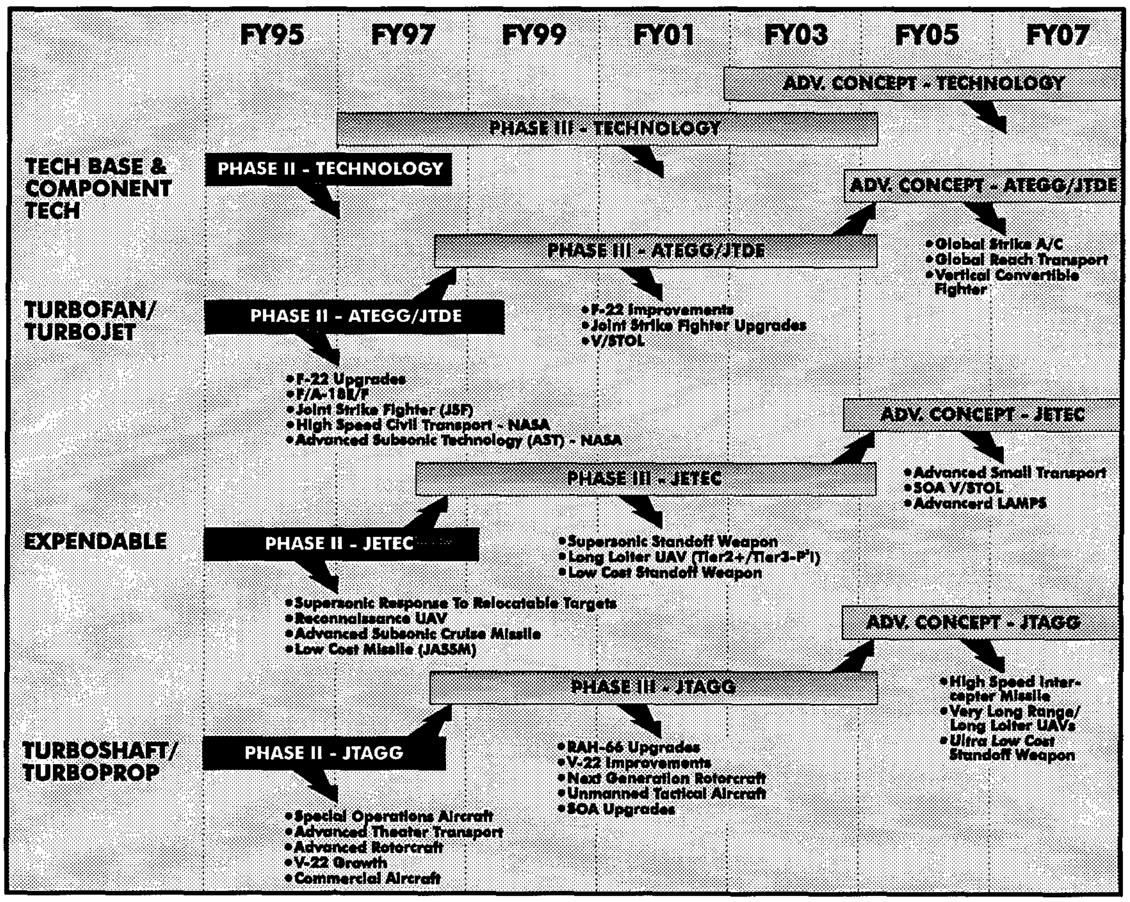

Figure 2.1: Thrust 1 – Turbine Engines

Although IHPTET Phase III is scheduled to be completed in 2003, the Air Force, Army, and Navy have defined plans for the next revolution in turbine engine technology capability – we call it **Advanced Concepts**. Payoff analyses are underway.

Historically, the propulsion system (engines plus fuel) accounts for 40% to 60% of aircraft takeoff gross weight and 20%-40% of the aircraft acquisition and operation costs. Accordingly, increasing engine performance and reducing engine costs are major contributors to improving future air platform capability.

In the nearer term, IHPTET technology is currently being transitioned to the following:

- F414 engine for the F-18E/F,
- F119 engine for the F-22,
- T406 engine for the V-22,
- T800 engine for the RAH-66,
- J407 engine for the Integrated Tactical Air Launched Decoy (ITALD), and
- Several civil engines such as the PW4084, GE90, FJ44, AE3007, and AE2100.

Future military transition opportunities include the following:

- Engine upgrades for the platforms listed above and the F-15, F-16, C-17, AH-63, UH-60, CH-47 and Tomahawk, and
- New systems such as the JSF, Common Light Vertical System Replacement, Ultra-low Cost Supersonic Standoff Weapon, Global Strike Aircraft, Global Reach Transport, Vertical Convertible Fighter, Uninhabited Fighter, or a long-range/loiter Uninhabited Air Vehicle (UAV).

IHPTET is also the primary building block for the National Transport Rotorcraft program and NASA's Advanced Subsonic Technology and High Speed Research programs directed specifically at civil engines.

To date, many user deficiencies involving turbine engine technology have been defined through the Technology Master Process. Those identified in the FY96 Air Force Modernization Planning Process – ASC Concept Call – Deficiency Data report are summarized in Table 2.1.

Table 2.1: Consolidated List of Deficiencies and User/TPIPT Reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Range / Endurance / Loiter Limitations	ACC / Aerospace Control, Air-to-Surface SOC / Special Operations Forces
Platform Acceleration (Thrust)	ACC / Aerospace Control, Air-to-Surface SOC / Special Operations Forces
Signatures of Aircraft Too High	ACC / Air-to-Surface, Rescue SOC / Special Operations Forces
Meet Noise and Emission Standards	AMC / Mobility SOC / Special Operations Forces
Lack of Engine Commonality	ACC / Rescue SOC / Special Operations Forces

In all cases, the IHPTET program is positioned to either deliver demonstrated technologies to the user or has an aggressive technology development plan underway – thereby lowering the user's technology introduction risk. Nearly all nearer-term needs call for "reduced engine acquisition cost and reduced cost of ownership" as a fundamental requirement along with increased durability, repairability, maintainability, supportability, and performance (thrust-to-weight and fuel consumption). To increase attention on cost reduction issues, programs have been structured to integrate IHPTET designs with advanced manufacturing processes to reduce all aspects of cost for new, derivative, and upgrade engines. Other methods for meeting the user defined deficiencies include the following:

- Maximize design application of new knowledge.
  - "Swept aero" provides higher pressure ratio in fewer compressor stages, a 3-5% higher efficiency, and greatly increased ruggedness. It is also an excellent example of a dual-use technology. If applied across the U.S. military and civil aircraft fleets, swept aero designs would save $1 billion per year in fuel use alone. The first fan design with IHPTET derived swept aerodynamics is now in production in the FJ44 engine. This engine is used by both a commercial business jet and an unmanned air vehicle (Dark Star).
  - "Super-cooled" turbine blade designs permit 300° F higher gas temperature for increased thrust, or 30% reduction in blade cooling air for reduced fuel consumption, or two-to four-fold increase in turbine blade life – all at a reduced manufacturing cost. The potential for a $3 billion total Air Force life cycle cost savings by using "super cooling" in the F119 (F-22 engine), F100 (F-15, F-16 engine), and F110 (F-16 engine) has resulted in a strong "user pull." We are accelerating the technology development and transition to meet near-term user needs.
  - Integrated low observable (LO) designs synergistically use IHPTET technology to reduce the manufacturing cost, weight, and performance penalties associated with stealth. Addressing LO requirements up front using an integrated product team (IPT) approach allows us to "build-in" rather than "bolt-on" stealth technologies, thus avoiding weight, cost, and maintainability problems.
- Address engine noise generation.
  - Noise can place military platforms at risk from an observability standpoint. Technologies such as our swept aerodynamics and variable cycle engine concepts address this deficiency.
- Use the same technology twice.
  - "Common engine cores" can be used in a wide range of applications from multiple fighter engines, to high bypass-ratio engines for military and commercial transports, to industrial and marine engines. Over 75% of the DoD turbine engine technology investments are applicable to civil sector needs.
  - IHPTET provides the core engine base for the Advanced Subsonic Technology (AST) and High Speed Research (HSR) programs – two premier U.S. investments by NASA that are part of the national/civil sector aircraft gas turbine technology development plan currently being defined by DoD, NASA, and industry.
- Tailor the engine performance during flight.
  - The Variable Cycle Engine (VCE) concept permits more efficient operation over a broader portion of the flight envelope. Specifically, the VCE concept should result in elimination of the augmentor with its attendant very high fuel usage and high signature, and the variable geometry exhaust nozzle with its high weight, complexity, and cost.
- Provide supersonic engine technologies.
  - Focusing on minimum cross section, low weight, increased thrust, reduced acquisition and ownership costs for the Joint Strike Fighter (JSF).
- Improve durability of current and future engines.
  - Eliminate/reduce high cycle fatigue (HCF) – one of the largest causes of fleet "stand-down," and
  - Avoid expensive midlife design changes by designing robustness into components.

- "Pump electrons" instead of hydraulic fluid, oil, or fuel.
  - Develop a "distributed control system" in which the accessories are located where they are needed rather than at the end of the power take-off shaft. This dramatically improves the reliability and maintainability of our engines – a prime user concern.
  - Eliminates the need for on-engine hydraulic systems, gearboxes, all associated plumbing, and some unique flightline specialists.
  - Internal engine starter/generator technology eliminates the central hydraulic unit, the power takeoff shaft (the "umbilical cord" between the engine and aircraft), and the gearbox which are another major source of maintenance actions.

In summary, all programs in this thrust are focused on meeting the IHPTET goals that, in turn, support the current user defined deficiencies. Special emphasis is being placed on resolving HCF durability issues and on reducing acquisition cost.

Goals

Time-phased goals have been defined for three classes of demonstrator engines:

- Large pilot-rated **turbofan/turbojet engines** for fighters, bombers, and transports;
- Smaller pilot-rated **turboprop/turboshaft engines** for trainers, rotorcraft, special operations aircraft and theater transports; and
- **Expendable engines** for cruise missiles and smaller, UAVs.

The specific IHPTET goals for each engine class are:

TURBOFAN / TURBOJET:		
■ Phase I (1991) +30% thrust/weight +100^{0}F combustion initiation temperature	■ Phase II (1997) +60% thrust/weight +200^{0}F combustion initiation temperature -20% production cost -20% maintenance cost	■ Phase III (2003) +100% thrust/weight +400^{0}F combustion initiation temperature -35% production cost -35% maintenance cost
TURBOSHAFT / TURBOPROP:		
■ Phase I (1991) +40% power/weight -20% SFC	■ Phase II (1997) +80% power/weight -30% SFC -20% production cost -20% maintenance cost	■ Phase III (2003) +120% power/weight -40% SFC -35% production cost -35% maintenance cost
EXPENDABLES:		
■ Phase I (1991) +35% thrust/airflow -20% SFC -30% cost	■ Phase II (1997) +70% thrust/airflow -30% SFC -45% cost	■ Phase III (2003) +100% thrust/airflow -40% SFC -60% cost

The time-phased approach of the IHPTET program allows for continuous technology transition, reduces technical risk, and defines interim milestones against which progress is assessed.

Examples of system level payoffs from achieving the challenging IHPTET goals include:

- Intercontinental range in an Air Launched Cruise Missile (ALCM)-sized missile,
- Five-fold increase in speed for turbine engine powered tactical missiles
- A 100% increase in range/payload for both attack aircraft and helicopters with enhanced maneuverability,

- A sustained Mach 3+ capability in an F-15-sized aircraft,
- 35% reduction in gross weight and production cost for a new fighter,
- A 100% increase in unmanned aerial vehicle endurance, and
- Greater range/payload capability in an F-18-sized STOVL aircraft.

Major Accomplishments

During the past year, we exceeded IHPTET's Phase I goals for turboshaft/turboprop and expendable engines. These include 40% increase in power-to-weight ratio and 20% reduction in fuel consumption. IHPTET Phase II is well underway in all three classes of engines and long lead technology efforts for Phase III have been awarded.

Cost goals for all three classes of engines are now in place. In support of the maintenance cost goal, a detailed technology development plan for HCF was defined and presented to the HCF S&T National Coordinating Committee. The HCF plan includes Air Force, Navy, and NASA efforts including three consortia with industry, namely, Forced Response, Instrumentation, and Damping.

Additional testing of key IHPTET technologies continued in dedicated structural/environmental advanced technology demonstrators. These durability "shakedowns" reduce the risk of technology introduction into future and current systems, lead to improved performance and capability, and ultimately result in significant life cycle cost (LCC) reductions. The payoffs for the F119 include system LCC savings of $420 million plus 10-20% thrust increase, 2-5% specific fuel consumption (SFC) decrease, and 15-20% cost and weight reduction for the augmentor and exhaust nozzle. For current engines, the payoffs include system LCC savings of over $1 billion plus doubled turbine life, reduced exhaust signatures, improved operability, and increased aircraft range.

Changes from Last Year

Our focus on achieving the challenging IHPTET goals is unwavering. Some programmatic changes have occurred to further demonstrate IHPTET technologies in response to recently defined user needs and renewed interest in UAV applications.

HCF continues to be an AFMC/ST Focus Area and has been raised to the highest levels within DoD. The National Coordinating Committee works to bound the problem and ensure that all necessary technology programs are being pursued.

The Air Force/Industry Affordability Working Group continued to accelerate efforts for reducing the acquisition, operation, and support costs of turbine engines. As a result of this group's recommendations, cost reduction goals are now in place for all three classes of engines. Production cost reduction, measured in dollars per pound of thrust and maintenance cost reduction, measured in dollars per thousand engine flight hours per pound of thrust, are the goals.

Of special note is the emergence of the JSF program – IHPTET technologies and demonstrations continue to serve as the foundation of the JSF propulsion effort, including the alternate engine. A new Advanced Technology Demonstrator (ATD) is being planned. Technology Transition Plans (TTPs) are in coordination.

The most profound change has been the renewed and expanded interest on advanced material development for IHPTET Phase III components. Special emphasis is being placed on turbine blades and disks along with last stage compressor disks.

Milestones

Selected milestones towards achieving the IHPTET goals are:

- Demonstration of Phase II variable cycle core – second quarter FY98
- Demonstration of Phase II combustion initiation temperature goal – fourth quarter FY99
- Demonstration of Phase II thrust-to-weight ratio – fourth quarter FY98
- Initial Phase II core structural evaluation (CAESAR) – third quarter FY97
- 2000 cycle structural evaluation of Phase II technology – first quarter FY98
- Active stall control engine demonstration – third quarter FY97
- Organic matrix composite fan blade engine demo – first quarter FY98
- High stage loading compressor rig test – first quarter FY98
- Rig test of trapped vortex combustor and integrated diffuser, injector, and flameholder – third quarter FY97
- Supercritical fuel delivery system rig test – first quarter FY99
- Core test of "supercooled" technology suite – third quarter FY97
- Spin rig test of dual web aisle – first quarter FY98
- Aero rig test of controlled area turbine nozzle (HPT & LPT) – second quarter FY98
- Fabrication/test of gamma titanium aluminide exhaust flap/liner – third quarter/fourth quarter FY98

Thrust Two – Fuels & Lubrication

User Needs

The Fuels and Lubrication thrust advances the pervasive technologies of aircraft and airbreathing missile fuels, combustion, lubricants, and lubrication systems. This thrust is structured in response to Mission Area Plans (MAPs) and associated weapon system user needs. These needs are identified through the Technology Master Process (TMP) that provides unified guidance to the Air Force laboratories, thereby providing a basis for focusing laboratory thrusts to address current and projected user needs. These needs/deficiencies are reported in the FY96 Air Force Modernization Planning Process – ASC Concept Call – Deficiency Data document prepared by Aeronautical Systems Center (ASC) for Air Force Materiel Command (AFMC). Weapon system deficiencies we are currently addressing are shown in Table 3.1.

Table 3.1: Consolidated List of Deficiencies and User/TPIPT Reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Increased range / endurance	ACC / Aerospace Control, Air-to-Surface
Improved reliability, maintainability, repairability	ACC /Aerospace Control, Air-to-Surface AMC / Mobility
Reduced signature (IR, visual, acoustic)	ACC / Aerospace Control, Air-to-Surface, Rescue SOC / Special Operations Forces
Thermal burden (cooling capacity)	ACC / Aerospace Control, Air-to-Surface, Intelligence, Surveillance, and Reconnaissance
Increased engine performance	ACC / Aerospace Control
Pollution compliance	ACC / Air-To-Surface AMC / Mobility

Our primary customers are the Air National Guard, Air Education and Training Command, Air Combat Command, Special Operations Command, Combat Search and Rescue, and Air Mobility Command. Their needs cross many command/theater boundaries.

Goals

Specific goals have been formulated to address the user needs shown in Table 3.1. These are quantified and timed phased with the IHPTET and HyTech programs.

- Improved fuels, aircraft thermal management, and cooling capability,
- Advanced combustor concepts, modeling and diagnostics, and reduced engine emissions,
- Improved engine lubricants and lubrication system mechanical components, and
- Increased reliability and supportability through reduced maintenance and lower life-cycle-costs.

Major Accomplishments

High Temperature Fuels:

During the past year, significant progress was made on development of a higher thermal stability JP-8 fuel (JP-8+100). While intended to provide additional margin in thermal stability and heat sink for future aircraft such as the F-22 and the Joint Strike Fighter (JSF), JP-8+100 continues to demonstrate significant benefits for current aircraft. Flight evaluations continue in F-15s, F-16s, T-37s, T-38s, A-10s, and C-130s. Flight evaluations in helicopters (UH-1, T-400 engine; H-53,

T64 engine; HH-60, T700 engine) at Kirtland AFB, NM as well as a C-141 flight test at the Air Force Flight Test Center, Edwards AFB are just beginning. At Sheppard AFB, TX, the use of the +100 additive package led to a 40% reduction in T-38 augmentor no-lights. For the other aircraft, maintenance personnel continue to report improved overall cleanliness for all engines on JP-8+100 versus regular JP-8. The F-15s at Langley AFB, VA will provide Air Combat Command the data necessary to determine operations & maintenance cost reductions and operational improvements.

Another important area of the JP-8+100 program includes material compatibility testing. This involves evaluating the impact (if any) of candidate +100 additive packages on metallic and nonmetallic materials (approximately 225) contained in the engine and airframe. To date, many of these materials have been tested with 5 different additive packages with no detrimental effects noted. This testing has an additional benefit in establishing a much needed materials compatibility database for JP-8 as well as for JP-8+100.

A limitation to use of the +100 additive packages is their ability to disarm existing filter-coalescer elements in ground fuel handling systems. This occurs due to the detergent/dispersant component in the +100 additives. A vigorous program to identify, test, and evaluate new technology compatible with JP-8+100 was initiated this past year. To date, a very promising technology passed several of these stages and is anticipated to enter field trials in the summer of 1997. This technology meets required water and dirt removal levels at operational fuel flowrates. Several additional vendors are developing their own alternatives, thereby laying the groundwork for a family of drop-in replacements and future competition to ensure the most economical and effective solution to this problem.

For future aircraft, thermal management will become an increasingly important concern. Building on the JP-8+100 work, development of a very high heat sink fuel (JP-900) has started to address this issue. JP-900 exploits the additional thermal stability and heat sink realized by taking JP-8+100 to the supercritical phase where the fuel has properties of both a gas and a liquid. As the temperature of the fuel is raised towards 900°F (hence JP-900), it undergoes different decomposition mechanisms that influence the life of fuel system components. Research in the past year indicated which fuel components can attack metal surfaces under supercritical conditions. Armed with this knowledge, design processes and development of fuel additives to eliminate or inhibit these adverse interactions were initiated.

Lubrication Systems:

Vapor phase lubrication (VPL) continues to demonstrate outstanding capability. The hottest bearing of a T63 engine was run exclusively on VPL in our High Speed Bearing Test Rig for a total of 21 hours. The bearing was run at speeds of 33,000-55,000 rpm, simulating engine speeds of idle to full military power. Bearing outer race temperatures ranged from 570°F to 780°F, which is considerably higher than the bearing design temperature of less than 300°F with standard liquid lubrication. Additionally, this bearing was run in the T63 engine itself for 7 hours at partial power. The bearing endured two cold starts and steady-state operation at 38,000 rpm and 670-700°F outer race temperature without incident. The standard M50 steel bearing was used, which normally operates with liquid lubrication at less than 300°F race temperature. This represented the first time that a gas turbine engine was run for an extended period of time with a VPL bearing at these temperatures. VPL is destined to revolutionize rotor support for advanced expendable and limited-life gas turbine engines, slashing 90% of the weight and complexity out of the lubrication system.

Carbon-carbon composites were shown to have promise as high temperature lubrication system materials. A prototype C-C composite cage was installed in the hottest bearing of the T63 engine and run exclusively on vapor phase lubrication. The test was conducted in-house at a top speed

of 52,000 rpm, simulating the T63 at cruise conditions. The bearing endured sustained operation at an outer race temperature of 860°F, nearly 600°F hotter than its design temperature with standard liquid lubrication. This bearing is composed of M50 steel races and balls and normally contains a silver plated 4340 steel cage, typical of current turbine engines. In previous rig tests, excessive wear of the standard steel cage was the primary factor in limiting the maximum bearing operating temperature with VPL to 700°F. The latest rig test was very successful, demonstrating the benefits of the new cage including much lower internal heat generation and significantly higher operating temperature capability. Follow-on rig and engine tests are planned for the 900-1000°F range, using hybrid bearings with T15 steel races, silicon nitride balls, and higher strength C-C composite cages.

All ceramic bearings are required for bearing temperatures above 1000°F in the JETEC III engines. Progress was made in lubrication silicon nitride bearings using inorganic cesium compounds as high temperature lubricants. Bearings achieved steady-state operation for periods up to 4 hours at environmental temperatures of 1200°F and bearing speeds up to 1.5 MDN. However, fracture of silicon nitride bearing races and inconsistent durability results with the cesium based lubricants continue to be problems. To enhance reliability, improved fracture tough ceramics and a more thorough understanding of the lubrication mechanisms are required.

Liquid lubricant development is focused on IHPTET propulsion technology goals. It is closely coordinated with lubricant base material and additive research efforts in the Materials and Processes technology area and with related government, academic, and industrial research centers. The temperature limit for standard ester-based liquid lubricants is approximately 400°F. To satisfy future IHPTET requirements, this limit must be raised necessitating exploration of different classes of lubricant basestocks. One such class is perfluoroalkylethers (PFAE). This class has a thermal stability limit of 650°F. Degradation products, however, are very corrosive to metal components. To exploit this class, new combinations of thermal stability additives and corrosion resistant materials in the lubrication system must be developed and readied for IHPTET sponsored demonstrator engine tests.

Excellent progress was made in the past year on a revolutionary advance in rotor support, namely magnetic bearings. In order to incorporate magnetic bearing technology into an IHPTET Phase III demonstrator engine, work completed indicates the need for a hybrid rotor support system. This system combines the operating temperature and rotor control attributes of magnetic bearings for routine engine load conditions with lightweight, robust auxiliary touchdown bearings for large transient loads. Such a combination will provide for the realization of IHPTET goals while exploiting the added benefits accruing from use of magnetic bearings in advanced engines such as active rotor control, active compressor stability, and blade tip clearance control.

Combustion:

A new in-house combustion research facility was developed to support joint programs between the government and several gas turbine engine manufacturers. This facility delivers heated air to the combustor at 0.75 lb/sec at temperatures up to 700°F through three separately controlled and metered air supply paths. Fuels available include JP-8, ethanol, propane, and methane. The computer data acquisition system is state-of-the-art with a programmable logic control interface. A full complement of pollutant emissions instrumentation and thermocouple probes, along with a two-camera video system, enables a wide range of research combustor testing. The first combustor tested in the facility is a 6-inch trapped vortex combustor sector being developed in conjunction with General Electric for their IHPTET Phase III program. This combustor will reduce combustor cost by 35%, reduce specific fuel consumption by 3%, improve altitude relight by 30%, and reduce pollutant emissions by a factor of 20 over the entire engine operating range.

One of the important disciplines in combustion lies in using sophisticated laser-based diagnostic systems to study the temperature, specification, and flow in simple flames and combustors. These techniques were exploited in a joint project with the turbine engine division to study operating turbomachinery nonintrusively. Pressure- and temperature-sensitive paints were successfully demonstrated in conjunction with the General Electric Swept Fan Assessment Rig (GESFAR) test program in the directorate's Compressor Research Facility. This new measurement capability provides a novel approach for rapidly mapping surface pressure and temperature distributions through optical, nonintrusive means with unequaled spatial and temporal resolution. During the GESFAR tests, we successfully demonstrated the acquisition of pressure and temperature measurements from individual rotor blades. Paints tested during this study included a commercially available Russian formulation as well as five new paints developed on-site. This test demonstrates that high quality measurements could be obtained even when the compressor is operating at full rotational speed. Under transonic conditions, the shock structure on the suction surface of the rotor blade is clearly revealed using pressure-sensitive paints. The temperature-sensitive paints responded to increasing blade tip temperatures with increasing rotational speed. This approach establishes a revolutionary measurement capability providing surface pressure and temperature of rotating and stationary compressor blades. It is an essential technique to resolving high cycle fatigue issues and quantifying aerodynamic performance of compressor blades.

We continued our work on next-generation fire suppression technology in partnership with Air Vehicles and Materials and Processes technology areas. The work is part of an 8-year, $46M research program to develop new fire suppression technologies for the replacement of Halon 1301 in fielded weapons systems. Halon has been the chemical of choice for fire suppression in most weapons systems. However, due to its high ozone-depleting potential, it was banned from production as of 1 Jan 94, under the Copenhagen Amendments to the Montreal Protocol on Substances that Deplete the Ozone Layer. The work here is to study bluff-body-stabilized (BBS) flames and the extent to which these flames impact fire suppression. BBS flames can be found in engine nacelles where plumbing, structural members, and other clutter cause recirculation zones to occur, producing very stable flames that are often difficult to extinguish. A laboratory-scale rig that simulates flow through engine nacelles, using input from airframe manufacturers, is currently being designed. Worst-case scenarios will be determined and fires will be extinguished using either gaseous, liquid, or solid suppressants. In concert with the experimental work, numerical modeling efforts are underway to better understand the flow physics involved.

Field Support:

In addition to developing technology to support future operational needs, our expertise has been in high demand in solving unexpected field problems. This past year we:

- Participated in the investigation of an F-15 crash where the cause was suspected to originate in the lubrication system,
- Worked with the Material Group Manager for aerospace fuels (SA-ALC/SF) in transitioning 12 bases to JP-8+100,
- Participated on an emergency support team investigating widespread cracking and burning of first stage stator vanes in T56 engines (C-130 aircraft) in the Tennessee Air National Guard,
- Participated on a depot-led team studying the problem of excessive flameouts with the J69 engine in T37 trainer aircraft, and
- Provided facilities and expertise to the National Transportation Safety Board investigation into the loss of TWA Flight 800.

Changes from Last Year

Last year, issuance of the final specification for improved JP-8 (JP-8+100) was slipped 2 years (from FY98 to FY00) because of the tendency of +100 additive packages to disarm existing filter-coalescers in ground fuel-handling equipment. With strong user endorsement and supplemental user funding, significant progress towards developing an effective filter-coalescer replacement compatible with +100 additives was realized. As a result, the anticipated final modification to the JP-8 specification to include +100 packages is now expected to occur in FY99. Follow-on programs such as JP-900 and endothermic fuels are concomitantly moved up.

Milestones

- The final specification for an improved JP-8 fuel (JP-8+100) will be released in FY99 with a qualified product list of additives.

Selected milestones documented in the DoD technology plan are:

- Demonstrate a 100°F increase in thermal stability and a 50% increase in heat sink capability for JP fuel by FY98.
- Demonstrate a five-fold increase in fuel cooling capability using JP-900 and a five-to-ten-fold increase in fuel cooling capability using alternative high heat sink hydrocarbon fuels (endothermics) by FY05.

Figure 3.1 outlines the specific timelines for milestones in the three major technology areas being pursued.

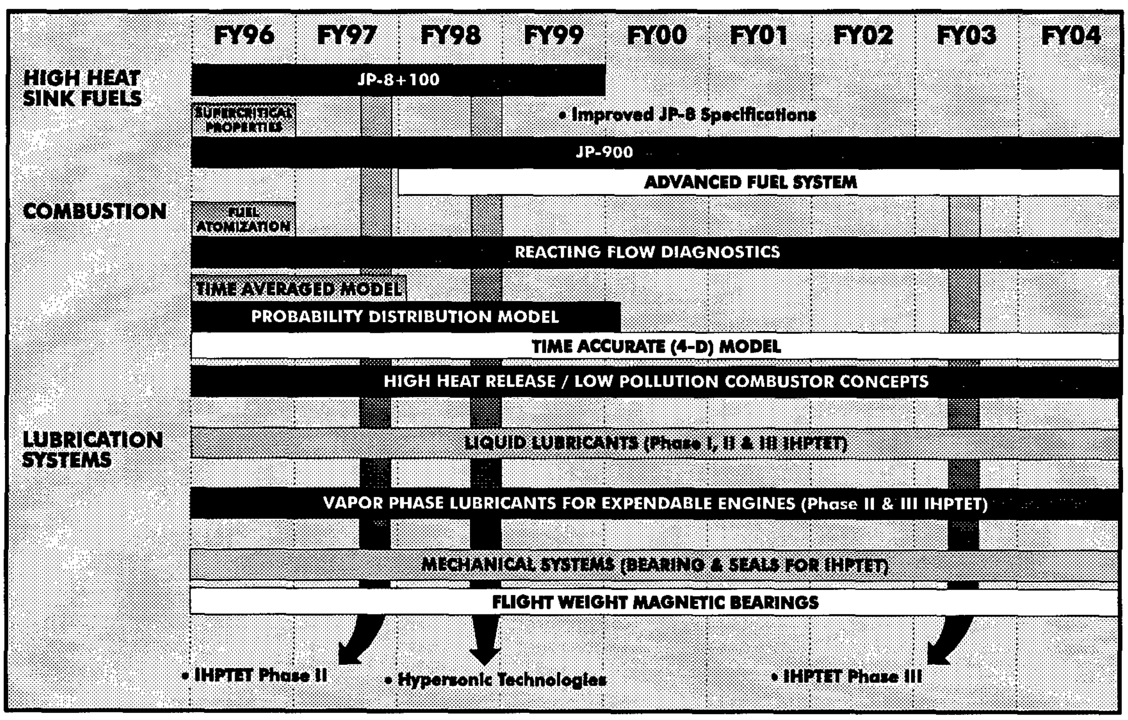

Figure 3.1: Thrust 2 – Fuels & Lubrication

- **High Heat Sink Hydrocarbon Fuels** are being developed to provide additional heat sink and thermal stability for future systems as well as reduce operational and maintenance costs, increase reliability and readiness in current and derivative engines. Additional JP-8+100 additive candidates are being sought and tested to assure wider availability and to meet the cost goal of no more than one-tenth of a cent per gallon of fuel. Research objectives have

been outlined to ensure the improved fuel will be available for fleet-wide transition by FY99. Responsive field support to help solve operational problems continues to be a high priority.

Development of an advanced hydrocarbon fuel with a thermal stability up to 900°F (JP-900) and endothermic fuels offer potentially significant improvements in aircraft thermal management with low maintenance and lighter fuel systems for high-speed air breathing missile propulsion systems. Endothermic fuels are essential for successful hydrocarbon scramjet and combined cycle engine concepts.

- **Combustion** research efforts are being conducted to reduce the risk and cost associated with developing affordable, durable, high performance turbine engines that operate efficiently within air pollution guidelines and have high thrust-to-weight and low specific fuel consumption. Research directed at providing high heat release capability for IHPTET Phase III combustors has been expanded to include the control of NO_x at high power and unburned hydrocarbons and carbon monoxide at low power.

  Replacement fire suppressant agents for the banned Halon 1301 will be evaluated to determine the optimum replacement and to better understand the extinguishing mechanism. This information is vital to specifying agent delivery systems and quantities of agent to be loaded into a particular fire suppressant system.

- **Lubrication Systems** address the challenge of supporting and controlling turbine engine rotors and the mechanical power extraction systems. System components are the lubricant, bearings, air-oil seals, dampers, and gears. Technology drivers include enhancing operability, maintainability, readiness for fielded engines, and meeting higher temperature and rotational speed requirements of IHPTET demonstrator engines.

  Fielded systems continue to benefit from advances in lubricant and bearing temperature tolerance, in oil diagnostic techniques for engine condition monitoring, and in contaminant identification technology for used oil segregation and recycling.

  Advanced systems require aggressive developments in component performance and durability, while making the systems more affordable. Specific requirements vary with application. For man-rated IHPTET applications, high performance, yet affordable systems with high durability and reliability are emphasized. Expendable IHPTET concepts emphasize low cost as well as high performance. Innovative rotor support system concepts must be employed to meet IHPTET Phase II and Phase III goals. Currently under development are systems to operate with high temperature liquid lubricants, various forms of solid lubrication, and vapor phase lubrication. Active magnetic bearings, another revolutionary concept under development, are also being developed for advanced technology demonstrator engines.

Thrust Three – High Speed Propulsion

User Needs

The High Speed Propulsion thrust is focused on supporting the new Air Force vision of "Global Engagement." In support of this vision, the High Speed Propulsion thrust provides Mach 0 to 8 air breathing engine technology for advanced missiles, aircraft, UAVs, and space launch vehicles. The thrust provides development and demonstration of unconventional air-breathing propulsion to ensure propulsion options for future high speed, rapid response air defense systems.

As the Air Force's only work in high speed airbreathing propulsion, this thrust plays a vital role in retaining the research base necessary to maintain our technological edge and to satisfy Air Force needs and deficiencies identified in the Mission Area Plans (MAPs). Aeronautical system needs we address are documented in the Air Force Modernization Planning Process Deficiency Data report and are summarized in Table 4.1. The Scientific Advisory Board New World Vistas study endorsed hypersonic propulsion as a key technology required to meet Air Force needs in the 21st century. Also, these technologies directly support the Air Force Core Competencies of Air and Space Superiority; Global Attack; Rapid Global Mobility; and Agile Combat Support.

Table 4.1: Consolidated List of Deficiencies and User/TPIPT Reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Increase missile kinematics and capability to destroy time critical targets	ACC / Aerospace Control
Ability to destroy targets from standoff ranges and ability to destroy time-critical targets	ACC / Air-to-Surface
Rapid response capability against theater and ballistic missiles	ACC / Theater Missile Defense
Cost effective space lift capability that enables timely support of military forces	AFSPC / Spacelift
Multiple high speed system concepts	ACC / Intelligence, Surveillance, and Reconnaissance; Counterair; and Suppression of Enemy Air Defenses AMC / Mobility

Achieving the potential payoffs for high speed airbreathing propulsion will mark a major step increase in weapon system performance and cost effectiveness. High speed and long range weapons will be critical to meet worldwide requirements as we continue to reduce overseas forces and forward basing.

To manage the required technology development programs, the High Speed Propulsion thrust is divided into three technology areas (subthrusts): ramjets, scramjets, and advanced cycle engines – each providing unique capabilities for the user.

Ramjet exploratory development efforts are no longer being funded under the Air Force's Science and Technology Program due to budget reductions. However, assessments focused on quantifying the benefits derivable from ramjet powered weapon systems are continuing. These studies are an integral part of the Dual Range Air-to-Air Missile program discussed in the Conventional Armament TAP. Specific improvements in air-to-air missile kinematic capability include increased no-escape zone, increased launch range, and reduced time-to-target. Additionally, high speed air-to-ground missiles will benefit through a 50% reduction in flyout

time-to-target (or double the maximum launch range) compared to conventional rocket powered systems.

Scramjet propulsion systems offer enormous payoff for future missiles, aircraft, and space launch vehicles. Their two- to three-times efficiency improvement over rocket engines enable the design and development of lighter engines and smaller hypersonic vehicles. These benefits can be realized, for example, through lighter air-to-ground weapons that rapidly attack time critical and hardened or deeply buried targets (lethality); provide long-range standoff capability (aircraft survivability); launch from tactical or strategic aircraft (combat flexibility); allow increases in loadout (force multiplication); and reduce requirements for overseas basing and aircraft (affordability). Mach 8 hydrocarbon fueled scramjet engines will provide the capability to attack highly mobile "SCUD-type" weapons from 300 nautical miles in less than 5 minutes or strike targets 1000 miles away in just 15 minutes. Future continental U.S. based scramjet propelled Mach 10 aircraft could reach any military target in 2 hours. Other high payoff scramjet applications include reusable launch vehicles that increase payload, thus providing more affordable access to space.

Advanced/combined cycle engine efforts are focused on developing pulse detonation engine (PDE) technology. This promising new engine cycle offers the performance of turbojets with automotive affordability. The inherent simplicity and low cost of the PDE make it ideally suited for missiles, drones, and UAVs. Additionally, PDE's offer the potential to outperform turbojets and ramjets at higher Mach numbers, providing superior capabilities for future systems. PDE technology is ready for component development and demonstration, based on successful SBIR efforts.

All Air Force High Speed propulsion efforts are coordinated and/or conducted jointly with NASA, Navy, and Army counterparts, as well as industry and universities, to provide a nationally unified high speed propulsion program. Figure 4.1 shows program development through the turn of the century and indicates points of transition to weapon system applications.

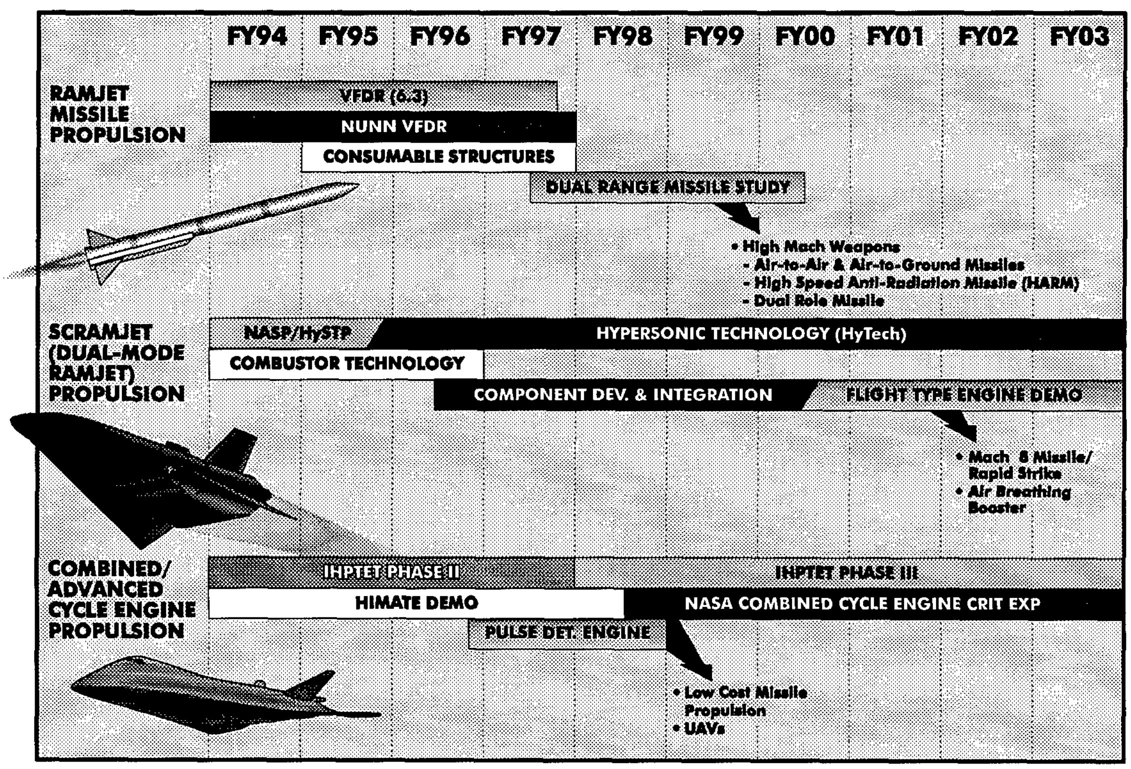

Figure 4.1: Thrust 3 – High Speed Propulsion

Goals

Provide Mach 0-8 storable fueled propulsion capability for the 21st Century.

This goal addresses the deficiencies and user needs identified in the MAPs and supports the Air Force Core Competencies required to maintain technological superiority. This will be accomplished by balancing performance, supportability, and costs of both upgrades and new high speed, long range propulsion systems.

Scramjet engine technologies using storable liquid fuels (e.g.,JP-10) will be developed for future missiles, aircraft, and space launch vehicles. Scramjet engine technology is being developed under the Hypersonic Technology (HyTech) program. The objective of the HyTech exploratory development (6.2) program is to develop and demonstrate technologies that "enable sustained hypersonic flight." The technology will be proven through ground-test demonstration of a vehicle-integrated, flight-type scramjet propulsion system for a fast reaction, Mach 8 air-to-ground missile. The major challenge is demonstrating scramjet system performance, operability, and survivability in an integrated freejet engine test. This effort will serve as a stepping stone to future developments of scramjet powered high Mach vehicles.

Also, the hydrocarbon fueled pulse detonation engine (PDE) is being evaluated under several Small Business Innovation Research (SBIR) programs. The PDE shows promise as a very low cost propulsion system for missiles, drones, and UAVs. Performance can be comparable to turbojets at low speed and better than ramjets at high speeds. Current efforts are focused on demonstrating engine operation and performance potential through subsonic proof-of-concept ground testing. Additional development of critical PDE components is underway to enable practical implementation of this engine cycle. These efforts include reducing predetonator volume to increase engine efficiency, and evaluating the use of a solid gas generator fuel system.

All engine systems being evaluated use storable hydrocarbon fuels. Use of these fuels will provide a dramatic advantage in supportability for future high speed systems. High Mach vehicles require fuels with a high heat sink capacity to cool hot engine and airframe components. Recent developments in high heat sink endothermic fuel technology (a fuel that absorbs a tremendous amount of heat through chemical decomposition) has enabled the use of conventional type jet fuels in high speed propulsion demonstration testing. Previous concepts and technologies were focused on using cryogenic hydrogen, requiring expensive "shuttle type" operations. With storable hydrocarbon fuels, airplane type operations for Mach 8 vehicles can be retained using current maintenance and fuel handling practices, enabling affordable and practical sustained high speed flight.

Major Accomplishments

Major FY96/97 accomplishments in high speed propulsion include:

- Established the HyTech Mach 8 hydrocarbon fueled dual-mode scramjet engine program. Scramjet contractors/engine configurations have been selected and engine fabrication and testing are underway.
- Demonstrated a baseline hydrocarbon fueled dual-mode ramjet/scramjet at Mach 4 to 7 flight conditions. Test results are very promising – combustion efficiency goals were achieved.
- Demonstrated flight weight Variable Flow Ducted Rocket (VFDR) component technology over the tactical flight envelope. Extensive ground testing included rocket-to-ramjet transition testing; testing at high Mach, long duration flight conditions (maximum thermal loads); and demonstrated the highest performance levels ever achieved in this configuration.
- Demonstrated flight weight VFDR engine support components. New torsion hinge assisted port covers were successfully demonstrated over the maximum and minimum actuation

pressure loads. The arm/fire device was successfully integrated into the engine and demonstrated initiation of all propulsive events.

- Demonstrated excellent combustion efficiency and fuel flow rate control for a boron loaded ducted rocket fuel that offers 50% more energy than the baseline VFDR.
- Demonstrated the feasibility of the PDE through a heavyweight proof-of-concept engine.
- Demonstrated an air-core enhanced turboramjet variable area mixer/combustor. Achieved combustion efficiency goals in minimal combustor length.

Changes from Last Year

The single major change to the High Speed Propulsion thrust is the virtual elimination of our primary ramjet and advanced/combined cycle engine development activities from FY98 and beyond. A limited amount of ramjet work will continue in the HyTech program and the turbo-based combined cycle engine work is being shifted to NASA sponsorship if funding is available.

Milestones

The high speed propulsion thrust has established the following milestones for each subthrust to provide a timely, logical path to meet stated needs and goals.

Ramjet engine milestones are focused on bringing current ramjet programs to a logical conclusion. Milestones include completing the VFDR Advanced Technology Demonstration program by documenting its final design and demonstrated performance (FY97). Joint international programs will document integrated engine performance of high energy boron fueled and passively throttled ducted rockets. Consumable port cover concepts for integral rocket ramjets will be demonstrated in the near term. Finally, an analytical feasibility assessment of the Advanced Airbreathing Dual Range Air-to-Air Missile will be completed (FY98).

Scramjet technology milestones are equally well established. Near-term activities include integrating an endothermic fuel heat exchange/reactor with an improved scramjet combustor to complete performance testing and expand the flight envelope up to Mach 7. Future milestones established under the new HyTech program include further developing dual mode scramjet engine components and engine flowpath (FY98); integrate scramjet engine components (FY00); and demonstrate scramjet engine performance, operability, and durability in an integrated engine freejet demonstration (FY02).

The thrust continues to explore and develop new and innovative high payoff propulsion cycles via SBIR programs. Technologies for a low cost, high frequency PDE will be demonstrated for missile applications (FY97). PDE predetonator volume minimization and alternate PDE fuels will also be demonstrated (FY98). A low cost air-turbo rocket (ATR) monorotor (compressor and turbine cast in one piece) will be developed and demonstrated. Finally, a solid fuel gas generator with low slagging characteristics will be developed and tested for use with the ATR monorotor.

Thrust Four – Aerospace Power

User Needs

The cost to produce, maintain, and support our high-tech weapon systems is one of the major issues the Air Force and DoD is facing. Technology options must be made available to ensure that aircraft designs are ultrareliable, easier to maintain, supported by less equipment and personnel, more survivable, lower in cost, and higher in performance. Additionally, global economics are forcing our current fleet into extended service lives. To support and maintain this aging fleet, technology retrofit options must be focused on reliability, maintainability, and supportability (RM&S) and be made available in a cost effective and timely manner.

The challenge then, is to retain our strength and air superiority – but to do so with less. To address this challenge, we are focusing resources under the More Electric Aircraft (MEA) portion of the More Electric Initiative (MEI) toward electrically-driven subsystems in replacement of more conventional, less reliable hydraulics, pneumatics, and mechanically-driven subsystems. This "more electric" concept is made possible by the successful development and demonstration of critical technical areas such as power generation, distribution components, energy storage, and subsystem interactions. Figure 5.1 illustrates these technical area demonstrations enabled by the enhancement of key power components.

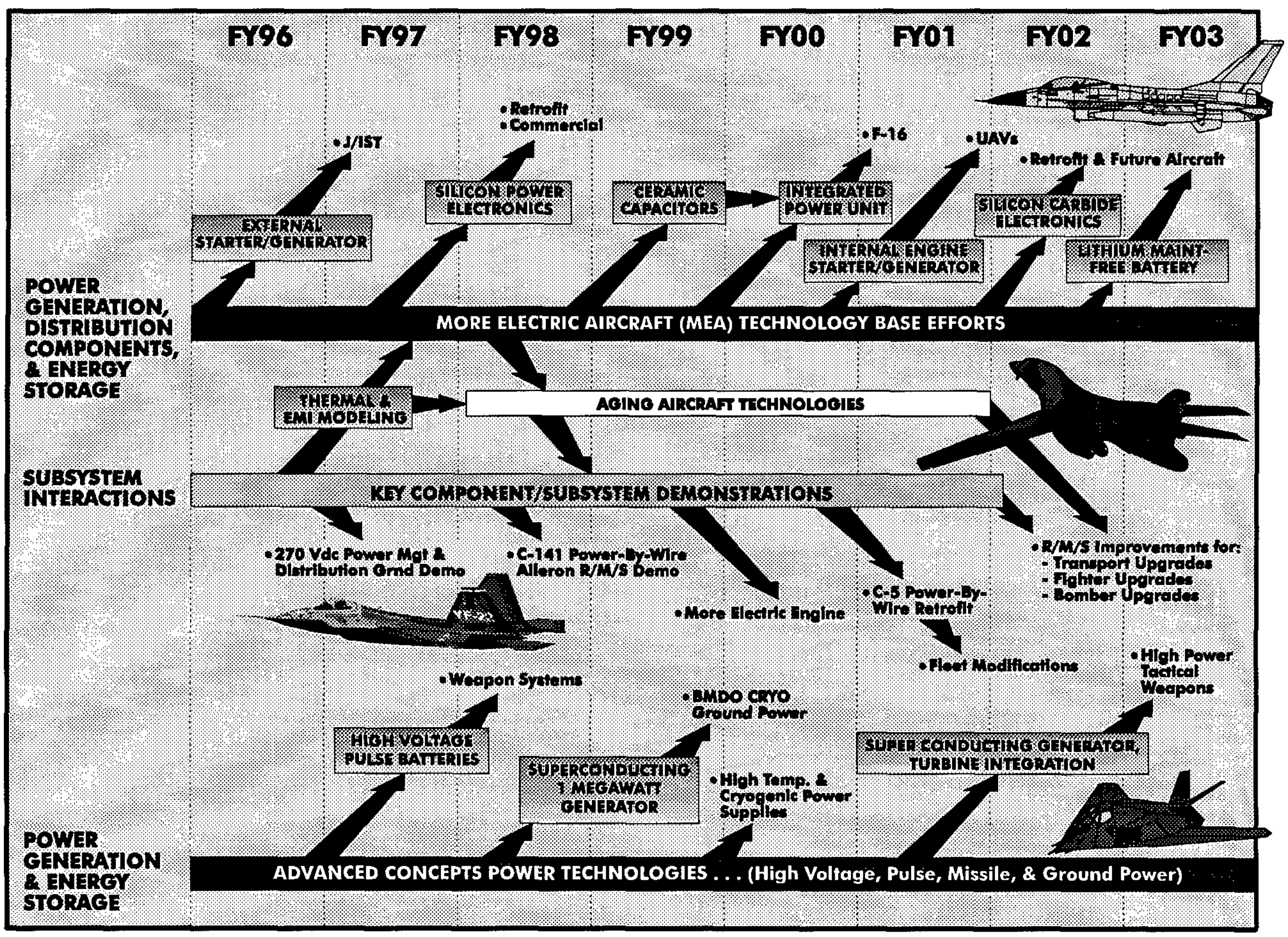

Figure 5.1: Thrust 4 – Aerospace Power

The "more electric" concept will not only reduce support equipment and costs, and improve our current aircraft effectiveness, but is also seen as the technology direction of opportunity relative to uninhabited aerial vehicles (UAVs), commercial aviation, electric vehicles, and numerous other commercial applications as well as a variety of advanced weapon concepts.

MEA and advanced concept power technologies are responsive to these weapon system needs, identified by Mission Area Plans (MAPs) and developed by Technical Planning Integrated Product Teams (TPIPTs) as part of the Technology Master Process (TMP). Table 5.1 shows a consolidated list of deficiencies we address that are documented in the FY96 Air Force Modernization Planning Process – ASC Concept Call – Deficiency Data report.

Table 5.1: Consolidated List of Deficiencies and User/TPIPT Reference

DEFINED DEFICIENCY	USING COMMAND / TPIPT
Excessive support equipment / logistics tail	ACC / Aerospace Control, Air-to-Surface
Antiquated / unreliable secondary power system	ACC / Aerospace Control, Air-to-Surface SOC / Special Operations Forces
Large, heavy short-life batteries	ACC / Aerospace Control SOC / Special Operations Forces
Low aircraft subsystem / component reliability (MTBF) / maintainability	ACC / Aerospace Control, Air-to-Surface AMC / Mobility
Lack of electronic cooling technology	SOC / Special Operations Forces
Hazardous waste removal / disposal	ACC / Air-to-Surface

More specifically, through high payoff technology efforts and an aggressive retrofit focus in the areas of power generation, distribution components, energy storage, and subsystem interactions, we will:

- **Reduce Support Equipment / Reduce Logistic Tail.** Relates to excessive manpower, support equipment, and readiness support package requirements necessitating significant airlift support; excessive and costly logistics tails and increased/complicated maintenance procedures required to sustain deployed force; lack of standardization across weapon systems, subsystems, and support equipment; and safety issues with handling and disposing of hazardous materials.
- **Improve Secondary Power Systems.** Detailed deficiencies include high failure rates for the jet fuel starter, central gear box, and airframe mounted accessory drives and "antiquated electrical generation and distribution systems."
- **Provide Long Life Maintenance Free Batteries.** Deficiencies in rechargeable battery low mean time between failure (MTBF) are causing unnecessary downtime; weight, volume and hazardous chemical composition of batteries for Special Operations Forces (SOF) aircraft and ground forces equipment is a problem; short nonrechargeable battery life for SOF are causing personnel to carry multiple spare batteries.
- **Reduce Maintenance / Increase Reliability.** Deficiencies cite low subsystem/component reliability (MTBF); 3-level maintenance support systems with increased pipeline spares requirements and manpower requirements; large maintenance and support costs as technology becomes obsolete in the aging C-5 fleet; and low reliability (MTBF) and maintainability of our fighter forces.
- **Improve Electronic Cooling.** Deficiencies indicate excessive demands on the aircraft during ground operations through overwork of the aircraft's environmental control system that

adversely affect deployability; and electronics cooling inefficiencies that cause lack of cooling for aircrew for premission ground operations.

- **Reduce Hazardous Materials.** Deficiencies cite hazardous materials problems with aircraft/weapon system/support systems associated with hazardous materials where removal, disposal, and replacement impacts safety of operations.

Goals

MEA and advanced concept power technologies are responsive to weapon system needs through technology efforts in each of the subthrust areas of power generation, distribution components, energy storage, and subsystem interactions. Goals for these areas include:

- Demonstrate a lubeless, gearless Internal Starter/Generator to eliminate the airframe mounted accessory drive transmission and its maintenance while increasing electrical power generation reliability (+900% for MEA Generation I in 1998, +1400 to 1900% for MEA Generation II in 2005).
- Develop and demonstrate the Integrated Power Unit (IPU) to reduce ground equipment by 30-50%, deployment load requirements by 25%, and eliminate potentially carcinogenic hydrazine.
- Develop high voltage electric power distribution and actuation subsystems to reduce and ultimately eliminate dependence on centralized hydraulic systems, resulting in reduced hydraulic system maintenance, fluid disposal, and cleaning fluid logistics and disposal.
- Increase electrical power distribution system fault tolerance by three-fold (3+ faults), and reliability by ten-fold via high temperature power electronics and utilization of smart, "prioritize/reconfigure," electrical load management centers.
- Increase maintenance free battery life from 2 to 20 years.
- Increase power electronic power density +100% by 1998 (MEA Generation I), and +200% by 2005 (MEA Generation II), while utilizing local, passive cooling that minimizes aircraft environmental control system requirements.
- Develop silicon carbide power electronic devices and other high temperature electrical components for a 6X increase in reliable operating temperature (up to 350° C).

Major Accomplishments

The MEA Integrated Power Unit (IPU) combines three aircraft power unit functions (main engine starting power, auxiliary ground power, and emergency power) into a single robust power unit design. Application of this power unit will result in significant reductions in aerospace ground equipment (AGE) while achieving projected reductions in Auxiliary Power Unit (APU) maintenance by more than 50%. The IPU program performed subsystem testing of a magnetic bearing/rotor support system at up to 99% of design full speed (55,000 rpm), which is 55% faster than any previous effort; the elimination of the lubrication system with the use of magnetic bearings is key to reductions in power unit maintenance. A second subsystem test demonstrating an air-cooled direct-drive high speed generator approach will be completed this fiscal year. Once subsystem/system tests have been completed, the generator and magnetic bearings will be integrated into an FY96 new start 6.3 program.

As an interim solution to emergency power generation requirements, a series of nontoxic monopropellants are being evaluated as possible replacement propellants for the hydrazine monopropellant used by the F-16 emergency power unit. Hydrazine, a known mutagen and suspected carcinogen, has received increased visibility as a hazardous material to be eliminated from the logistics tail. During the past year the number of formulations has been reduced to one likely candidate and optimization of the chemical percentages has been achieved. Recent

manufacture of a full-scale test rig will allow quantification of the kinematics for this final formulation.

The Power Management and Distribution for More Electric Aircraft (MADMEL) program has continued to directly support the F-22 System Program Office (SPO) in terms of advanced, 270-volt power distribution technologies via active F-22 SPO participation in the program activities and direct test/evaluation of F-22 configured components. Critical design has been accomplished, and the program is now completing the subsystem fabrication phase.

An alternating current, electrical load management center is being transitioned to two aircraft platforms. This technology has been selected to be used on the Advanced Hercules II (C-130J) and by Bombardier Aerospace Group – North America on their long range high speed Global Express business jet. Electrical load management has embedded intelligence that provides fault tolerance and improved reliability for the power system. On the C-130J, this technology enabled the removal of one person (the flight engineer) from the cockpit, resulting in a two-person flight crew. The C-130J rolled out in October 1995, underwent extensive ground and taxi tests, and performed its 2-hour maiden flight on 5 April 1996, where the technology performed without incident.

Great progress has been made in the subsystems interactions area via the C-141 Electric Starlifter program. The Electric Starlifter is a C-141A owned and operated by the Air Force Flight Test Center at Edwards AFB which has been modified with electric actuators on both ailerons. Electric actuators will reduce the cost of maintaining transport aircraft while increasing their reliability and represents a benchmark in the MEA initiative toward electrically-driven subsystems. The Electric Starlifter has completed 20 hours of air worthiness flight testing and approximately 400 of 1,000 planned operational flight hours. The operational phase of this program is a first of its kind and is providing invaluable data on improved reliability and maintainability.

In summary, these science and technology programs continue to receive strong endorsements from the Air Combat Command, Air Logistics Centers, numerous SPOs, and other Air Force Materiel Command organizations. In direct response to DoD and Air Force guidance and recommendations from the Scientific Advisory Board (SAB), the aircraft power focus continues to emphasize MEA technologies that take advantage of the greater reliability and performance characteristics offered by electrical and electronic components.

Changes from Last Year

The focus of all MEA programs has shifted toward MEA Generation II identified developments including the internal-to-the-turbine integral starter/generator. The external version of the integral starter/generator has successfully transitioned to the Joint Strike Fighter (JSF) initiative's Joint/Integrated Subsystems Technology (J/IST) demonstration. Efforts toward the "internal-to-the-turbine engine" version are now underway with both major turbine engine manufacturers and are managed in both this thrust and the Turbine Engine thrust. In January 1996, the SAB strongly recommended that development and demonstration of the internal starter/generator be accelerated. This technology has been long identified as a cornerstone to the implementation of electrically-based aircraft subsystems and the ultimate capability to eliminate centralized hydraulics.

Silicon Carbide (SiC)-based electronics may have the capability to greatly enhance the high temperature, reliable operation of an MEA. As such, it has been identified as a target technology for Generation II capabilities and has received strong attention from the Defense Advanced Research Projects Agency (DARPA) and from Director of Defense Research and Engineering (DDR&E). In conjunction with Wright Laboratory's Materials Directorate, DARPA has focused

on development of high quality, semiconductor grade SiC material and plans to use this new material for the aggressive development of power electronic devices with our thrust as their technical lead. The benefits of this technology to military systems are so significant that DDR&E has now established a task force to identify key demonstrations of the insertion of silicone carbide. The task force's recommendations emphasize SiC power electronics for the MEA and other electric conversion development within DoD.

Milestones

Specific milestones contained within the MEA initiative and advanced concepts power include:

- FY97, Complete inservice evaluation of the C-141 electric aileron actuators.
- FY97, Complete advanced inverter, and demonstrate MEA Generation I inverter goals.
- FY98, Complete fabrication of the internal engine starter/generator rig demo hardware.
- FY98, Motor, actuator and breadboard motor drive electronics fabrication, integration and testing for Advanced Motor Drive development.
- FY98, Complete lithium rechargeable cell (20, 50 AHR...~100 Whr/kg); cell-level demo
- FY98, Complete MEA power distribution ground demo (MADMEL); demo MEA Gen I objectives
- FY99, Ceramic materials for dielectrics available for high temperature, high power electric current filter applications.
- FY99, Complete engine rig testing of the internal starter/generator.
- FY02, Demonstrate a 100-ampere, 600-V, 572° F silicon carbide switch.

Glossary

ACC	Air Combat Command
AF	Air Force
AFAE	Air Force Acquisition Executive
AFB	Air Force Base
AFMC	Air Force Materiel Command
AFMPP	Air Force Modernization Planning Process
AFS&T	Air Force Science & Technology
AFOSR	Air Force Office of Scientific Research
AFSPC	Air Force Space Command
AGE	Aerospace Ground Equipment
ALC	Air Logistics Center
ALCM	Air Launched Cruise Missile
AMC	Air Mobility Command
ANG	Air National Guard
APSI	Aircraft Propulsion Subsystem Integration
ASC	Aeronautical Systems Center
ATD	Advanced Technology Demonstrator
AST	Advanced Subsonic Technology
ATEGG	Advanced Turbine Engine Gas Generator
ATR	Air-Turborocket
BBS	Bluff-Body-Stabilized
C^4I	Command, Control, Communications, Computers, and Intelligence
CAESAR	Core and Structural Assessment Research
CRDA	Cooperative Research and Development Agreement
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research & Engineering
DMR	Dual-Mode Ramjet
DoD	Department of Defense
DTAP	Defense Technology Area Plan
DTO	Defense Technology Objective
FMRAAM	Future Medium Range Air-to-Air Missile
GESFAR	General Electric Swept Fan Assessment Rig
HCF	High Cycle Fatigue
HPT	High Pressure Turbine
HSR	High Speed Research
HySTP	Hypersonic Systems Technology Program
HyTech	Hypersonic Technology
IHPTET	Integrated High Performance Turbine Engine Technology
IPT	Integrated Product Team
IPU	Integrated Power Unit
IR&D	Independent Research and Development
IRR	Integral Rocket Ramjet
ITALD	Integrated Tactical Air Launched Decoy
JETEC	Joint Expendable Turbine Engine Concept
J/IST	Joint/Integrated Subsystems Technology
JP	Jet Propulsion
JSF	Joint Strike Fighter
JSTAR	Joint Strategic Target & Recognition System
JTAGG	Joint Turbine Advanced Gas Generator
JTDE	Joint Technology Demonstrator Engine
LCC	Life Cycle Cost
LO	Low Observable
LPT	Low Pressure Turbine
MADMEL	Power Management and Distribution for More Electric Aircraft
MAP	Mission Area Plan
MDN	Millions of Dynes (bearing diameter times shaft rotational speed)
MEA	More Electric Aircraft
MEI	More Electric Initiative
MTBF	Mean Time
NASA	National Aeronautics and Space Administration
NOx	Nitrous Oxides
NWV	New World Vistas
PDE	Pulse Detonation Engine
PFAE	Perfluoroalkylethers
RAMTIP	Reliability & Maintainability Technology Insertion Program
R&D	Research & Development
RM&S	Reliability, Maintainability, and Supportability
S&T	Science and Technology
SAB	Scientific Advisory Board
SBIR	Small Business Innovation Research
SFC	Specific Fuel Consumption
SiC	Silicon Carbide
SOC	Special Operations Command
SOF	Special Operations Forces
SPO	System Program Office
STOVL	Short Takeoff/Vertical Landing
TAP	Technology Area Plan
TARA	Technology Area Review and Assessment
TEO	Technology Executive Officer

TIPs	Technology Investment Plan
TMP	Technology Master Process
TPIPT	Technical Planning Integrated Product Team
TTO	Technology Transition Office
TTP	Technology Transition Plan
UAV	Uninhabited Air Vehicle
Vdc	Volts Direct Current
VCE	Variable Cycle Engine
VFDR	Variable Flow Ducted Rocket
VPL	Vapor Phased Lubricant
WL	Wright Laboratory

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